Optics for a new SOB made of Fused silica blocks

J. Va'vra, SLAC

BaBar DIRC -> FDIRC prototype -> FDIRC with a new SOB

Content of this talk

- A comments on the BaBar DIRC and its optics
- A couple comments on the FDIRC Prototype and its optics
- **Optics of the new SOB**

New optical design of SOB

- **Aim:**

  - Design a new SOB, which would be **~10x smaller** than the BaBar SOB.

  - Detectors have ~**10x better time resolution** than BaBar DIRC

  - Have **similar or better** Cherenkov angle resolution than BaBar

  - Use **highly pixilated** MaPMTs detectors

  - Each bar box will have its own SOB, which is optically independent

  - Plan is to make each SOB piece out of a single piece of Fused silica

  - No more water leaks, no water corrosion, no maintenance of the water system, no moderation of fast neutrons in ~1800 gallons of water

Various DIRC concepts

B. Ratcliff ,SLAC-PUB-5946, 1992, NIM., A595(2008)1-7 and recently "Simple considerations for the SOB redesign for SuperB", SuperB meeting, http://agenda.infn.it/categoryDisplay.py?categId=38, March 20, 2008.

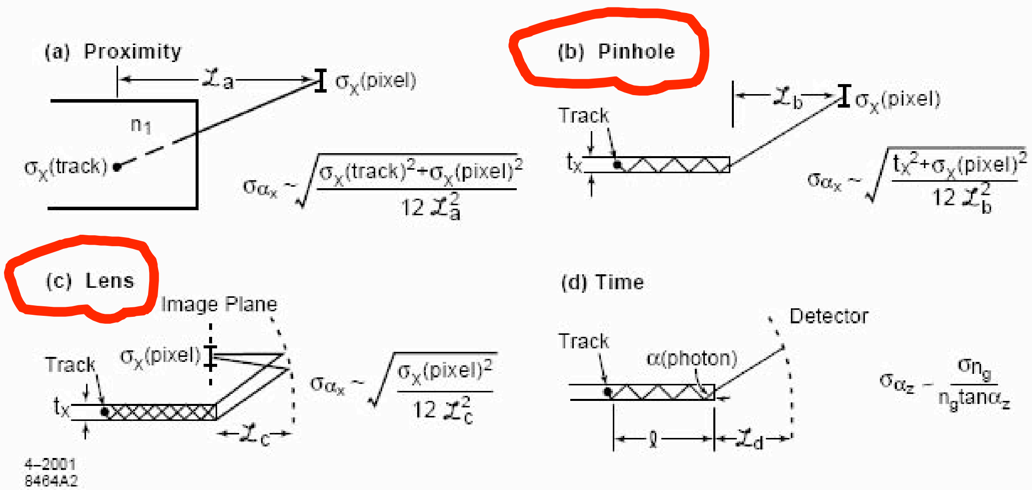
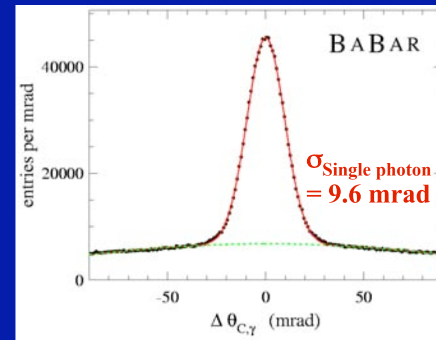


Figure 3. Illustrations of four different DIRC imaging schemes: (a) proximity (b) pinhole (c) lens (d) time. Simple estimates of the imaging and detector part of the resolution obtained on the photon angle in the projection shown are noted for each scheme. These estimates should be treated as pedagogic approximations. For simplicity, all position and detector resolutions are treated as though they are pixelized, and the indices of refraction of the Cherenkov radiator and the imaging region are taken to be the same. The time dimension resolution estimate (d) is given for the dispersion limiting case where the time measurement resolution itself is not the limiting factor. Sec. 4.3 describes the more general case.

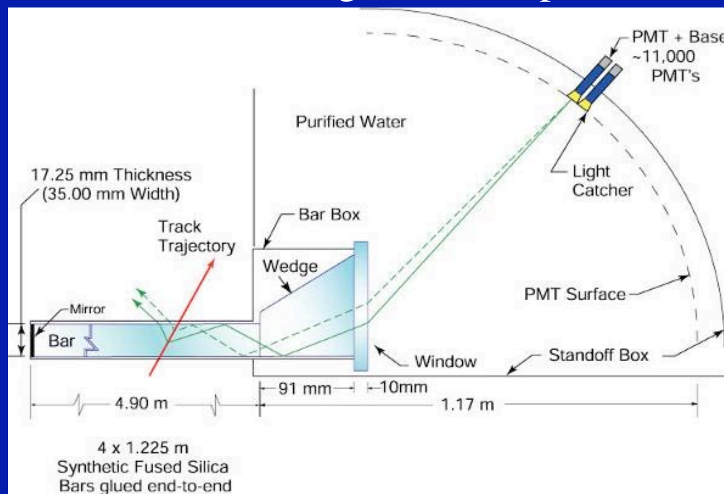
- **Spreadsheet calculation is useful to get the feel for the design.**

BaBar DIRC

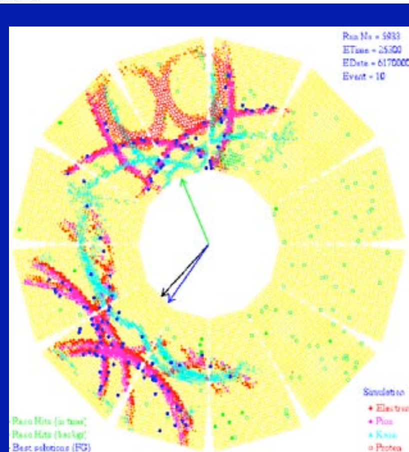
(DIRC NIM paper, A538(2005)281-357)



As we will see, the wedge will complicate things:



MC simulation of DIRC images in BaBar:



- **Resolution per photon:**

- $\Delta\theta_{track}$ ~ 1 mrad
- $\Delta\theta_{chromatic}$ ~ 5.4 mrad ←
- $\Delta\theta_{transport\ along\ the\ bar}$ ~ 2-3 mrad
- $\Delta\theta_{bar\ thickness}$ ~ 4.1 mrad ←
- $\Delta\theta_{PMT\ pixel\ size}$ ~ 5.5 mrad ←

Total: $\Delta\theta_c^{photon}$ ~ 9.6 mrad

- **Resolution per track:**

(N_{photon}~20-60/track)

$$\Delta\theta_c^{track} = \Delta\theta_c^{photon}/\sqrt{N_{photon}} \otimes \Delta\theta_{track}$$

$\Delta\theta_c^{track}$ ~ 2.4 mrad on average

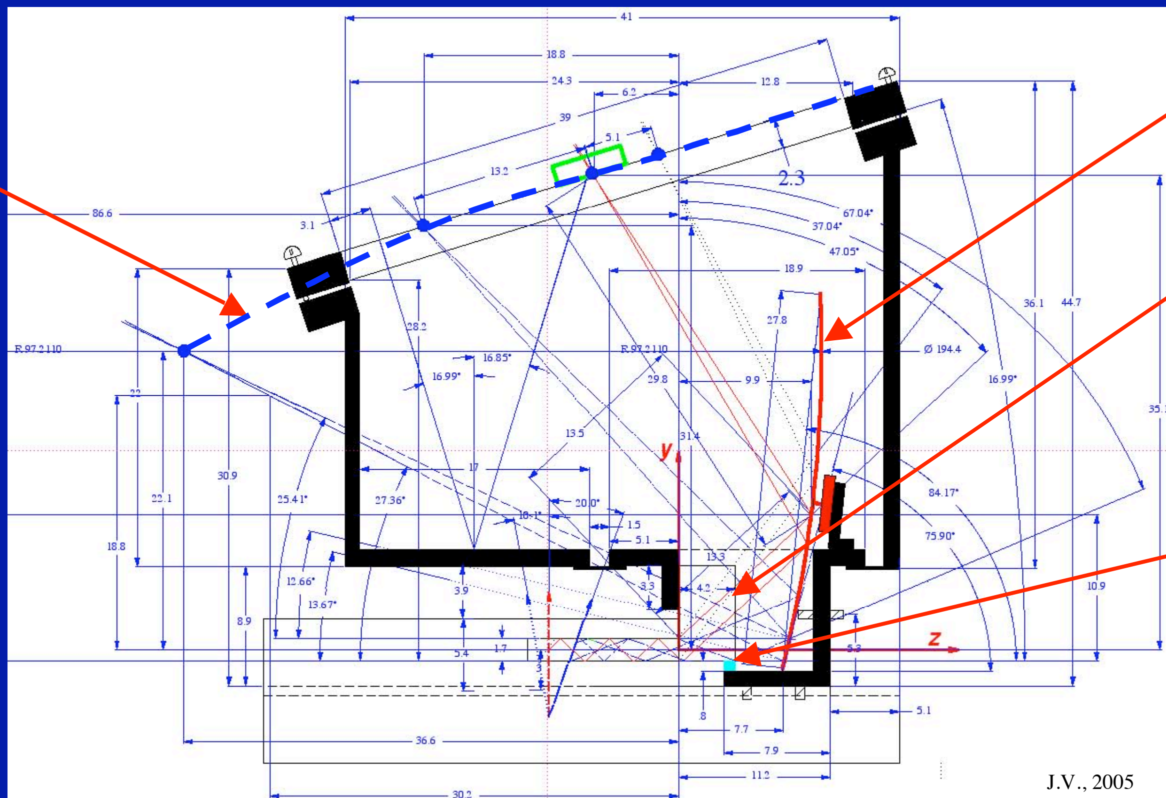
- BaBar Cherenkov images are simple, typically extending over 2 sectors.
- The images do not show the **secondary effects** due to the wedge or kaleidoscopic effects due to bar.

FDIRC prototype optics design

(FDIRC: (a) SLAC-PUB-12236, (b) SLAC-PUB-12803, (c)NIM, A595(2008)274, (d) SLAC-PUB-13464)

A true focal plane is not exactly flat:

FDIRC prototype:



Spherical mirror

Bar ends with a quartz block which reflects a downward aiming image up

This blue support block is mirrorized on one side

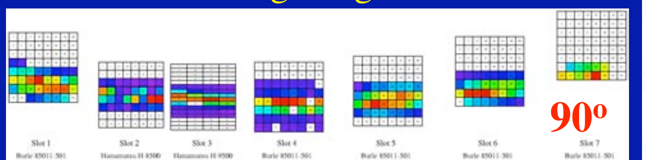
- **Geometry: Focal plane chosen so that 6mm x 6mm pixels yield the same θ_c resolution as BaBar DIRC.**
- **FDIRC prototype originally designed with a Vellum drafting program by manual ray-tracing.**
- **Transfer the design into the Mathematica and do ray tracing there.**

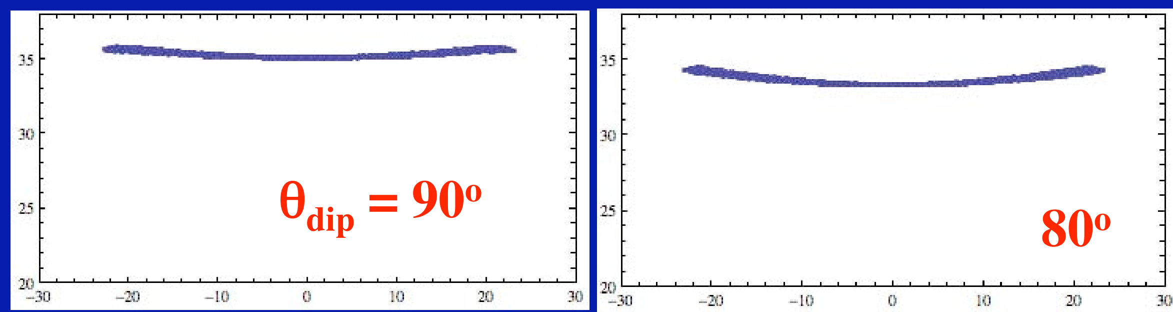
FDIRC prototype Cherenkov ring images

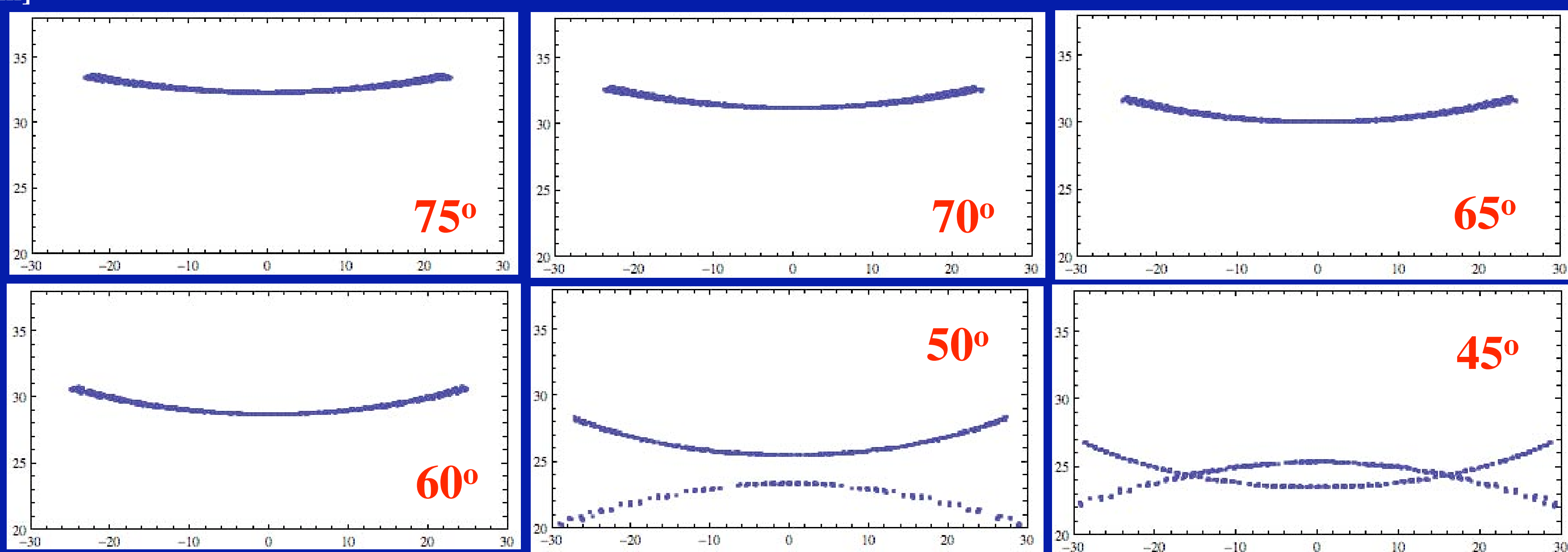
J. Va'vra, SLAC-PUB-13464, 2008 & Elba SuperB workshop, 2008

Calculated images using ray tracing in Mathematica:

Real FDIRC ring image in the beam:





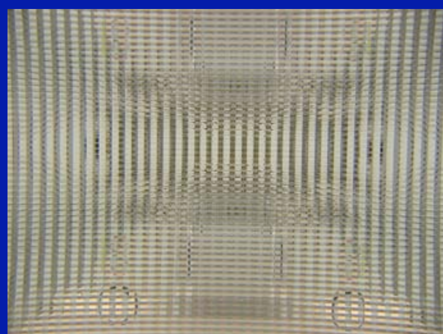


- **With no wedge, the ring images are simple. But there is a caleidoscopic effect !**

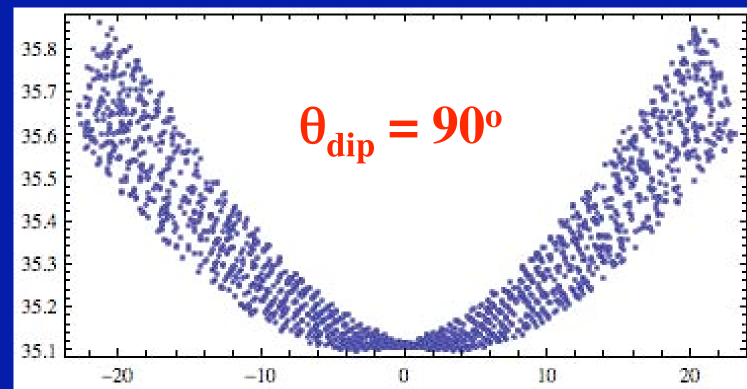
Details of a ring image for FDIRC prototype

J. Va'vra, SLAC-PUB-13464, 2008 & Elba SuperB workshop, 2008

Kaleidoscope looking into a bar:



Cherenkov ring image - FDIRC prototype:

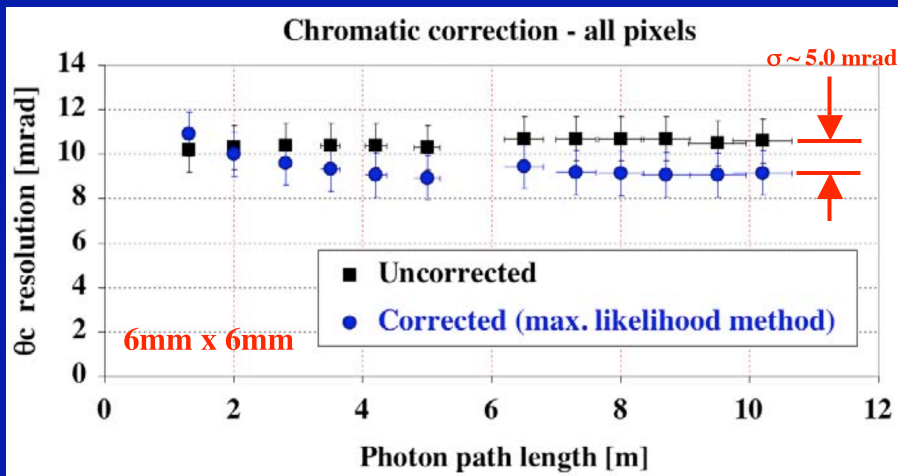


- **Kaleidoscopic wiggles in the image come from the bar rectangular bar structure.**
- **However, we would see this patten only if we would have large number of Cherenkov photons and look at the ring image with a resolution of our eyes. In practice, we do not see it, but the resolution is affected by this effect.**

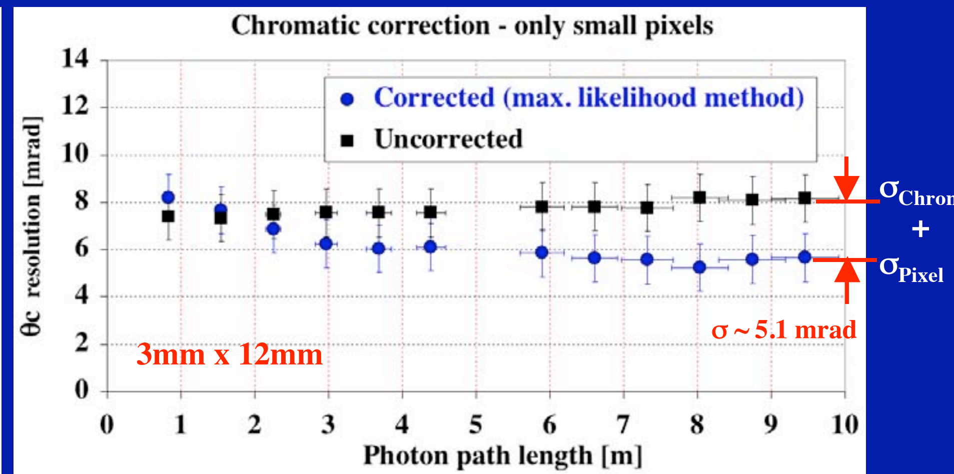
θ_C resolution = f(Chromatic correction & pixel size)

(SLAC-PUB-12803)

All pixels:



3mm pixels only:

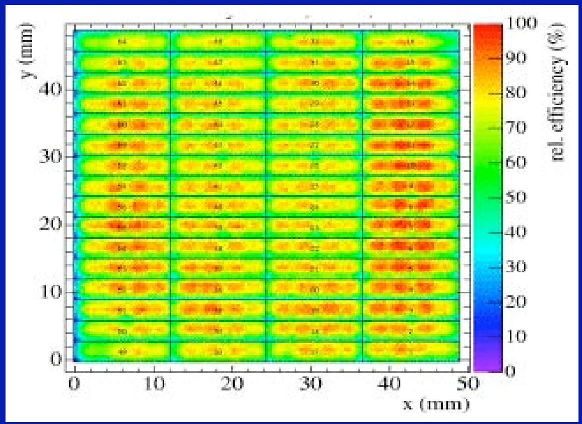


- **This device was the first Cherenkov detector to demonstrate how to correct chromatic dispersion.**
- **The chromatic correction starts working for Lpath > 2-3 meters due to a limited timing resolution of the present photon detectors. The maximum likelihood technique does better for short Lpath than other methods.**
- **Smaller pixel size (3mm) helps to improve the Cherenkov angle resolution; it is our preferred choice.**
- **The results consistent with the MC prediction.**

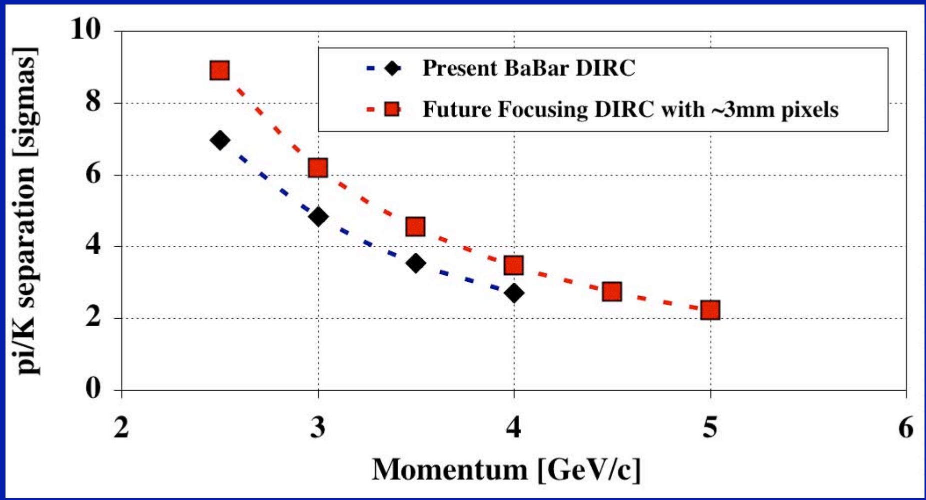
FDIRC resolution

(SLAC-PUB-12803 & NIM A595(2008)274)

H-9500 MaPMT with 3x12 mm pixels:



Expected performance of a final device:



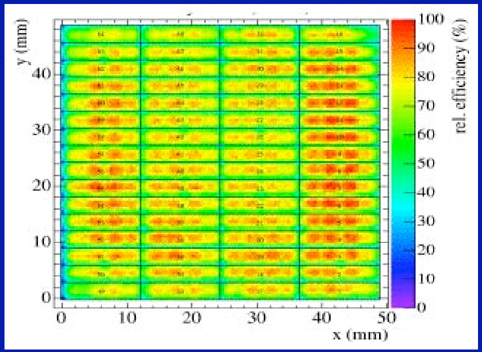
Clearly, we prefer to use 3 x 12 mm pixel size

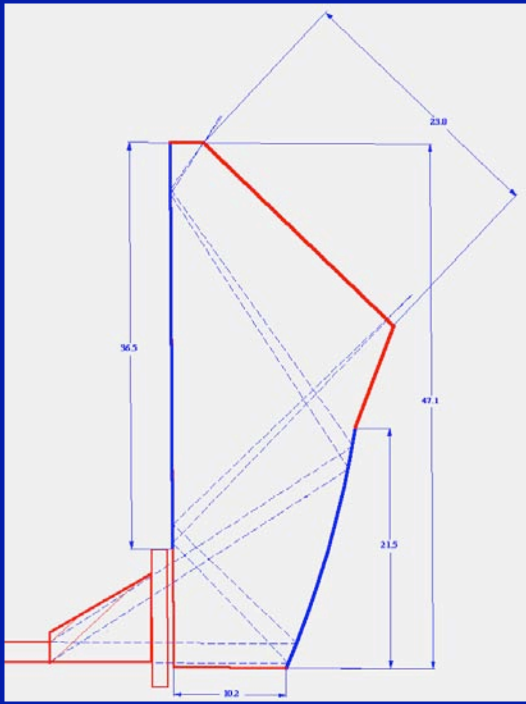
LDRD proposal

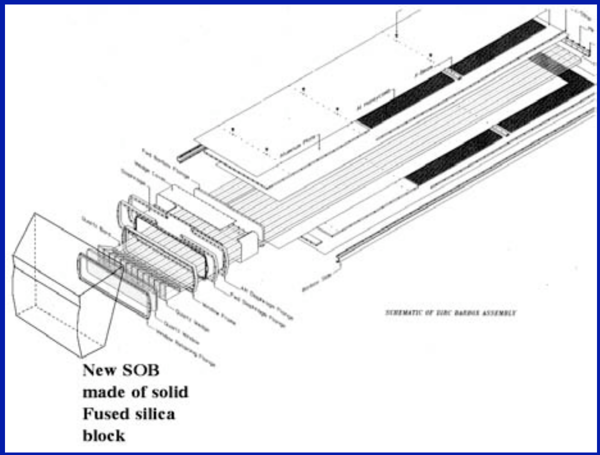
(submitted to the lab by J. Va'vra, B. Ratcliff and D. Leith)

SLAC National Accelerator Laboratory
Laboratory Directed Research and Development Proposal

4/29/2009



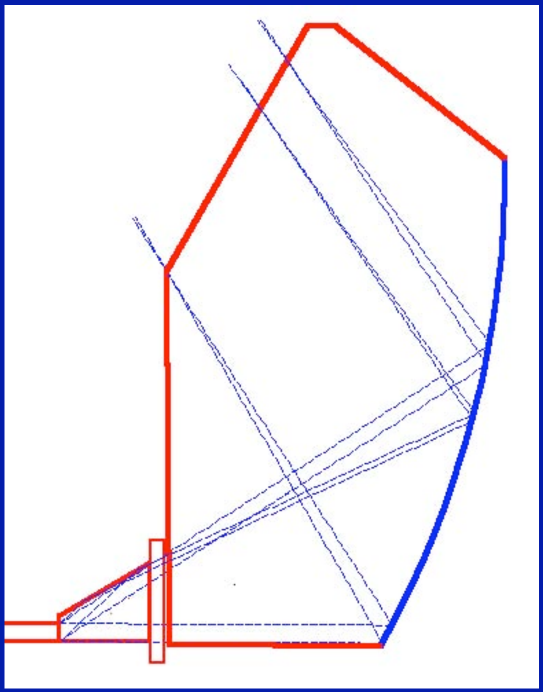




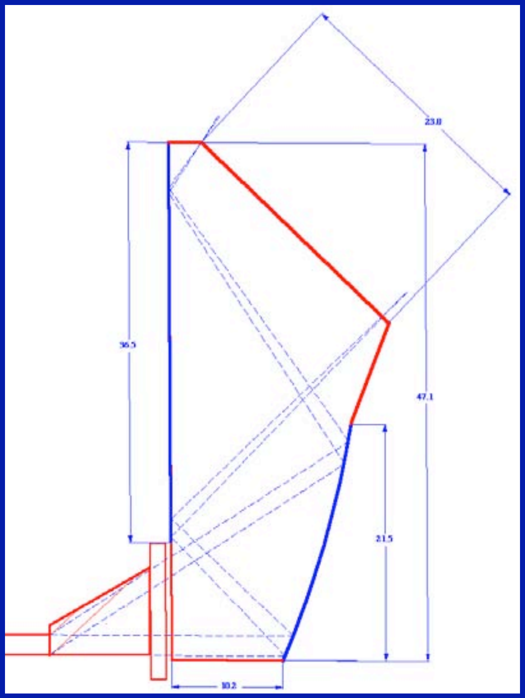
- **Pictures as submitted to the LDRD proposal**

Folded or not folded ?

Non-folded design



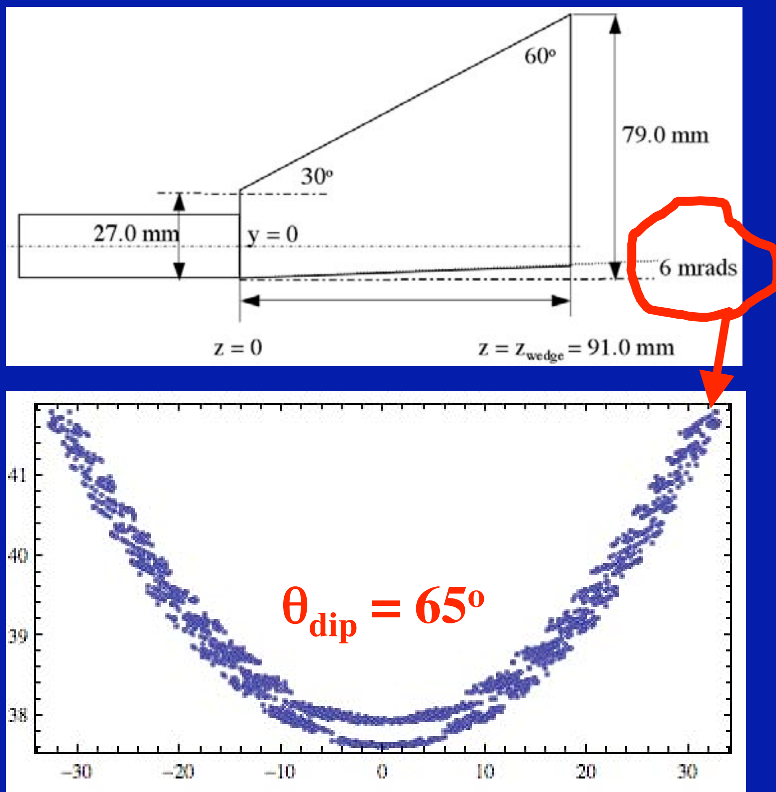
Folded design



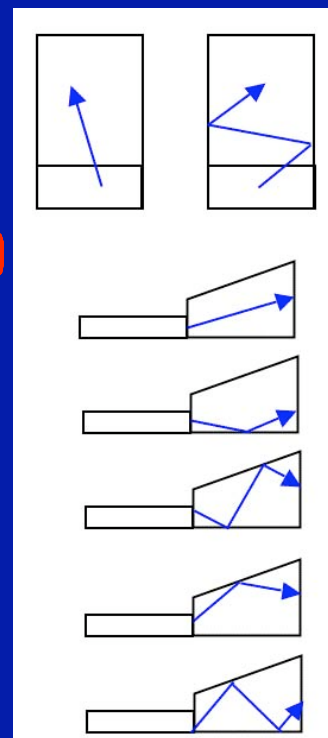
- Generally, the folded designs are smaller, therefore cheaper.
- The folded designs have good access to the detector (in case of BaBar).
- However, the folded designs have some complication near mirror edge.

Wedge and SOB sides

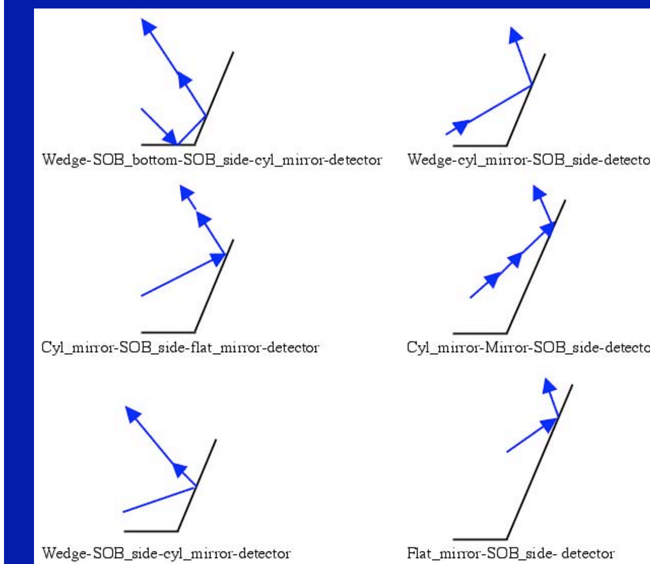
Wedge geometry:



Wedge reflections:



SOB side reflections:



- **Wedge and SOB side reflections complicate images.**
- **For example, the wedge reflection from the bottom creates double images, which is observable only for large number of photons and with high resolution detector.**

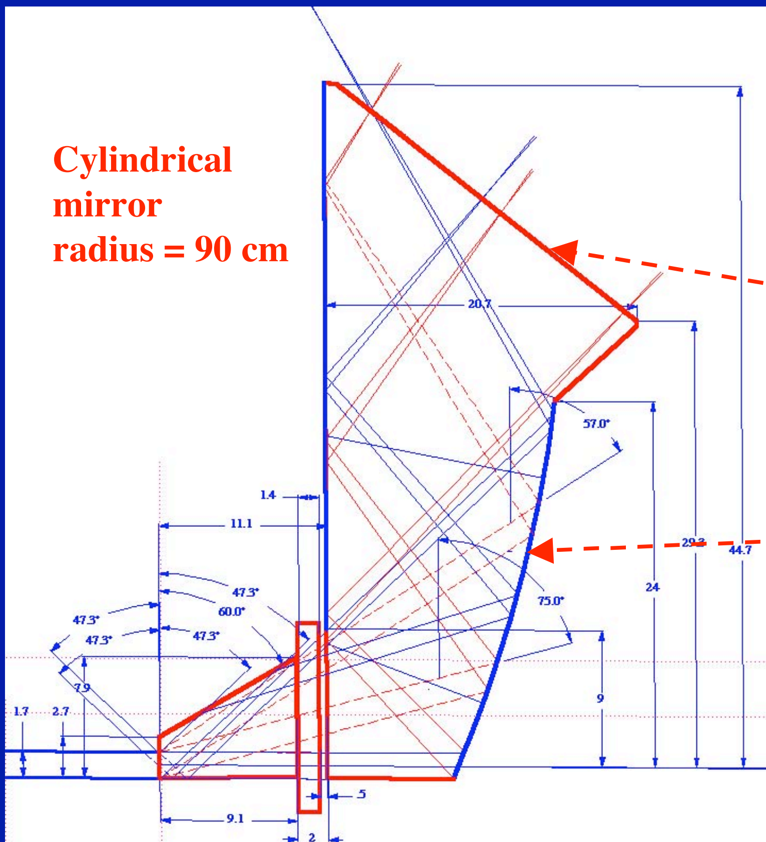
A few comments about the design procedure

- **Similar design steps as used in the FDIRC prototype**
- **Procedure:**
  - Ray trace manually first - here one “fiddles” with various geometrical parameters
  - Ray trace each photon, step by step, bounce by bounce, in the Mathematica code (do not use any packages such as Optica) - here one tries to verify the manual ray tracing step.
  - Scale the overall size from the BaBar DIRC using the pixel ratios
  - Go away from a spherical mirror, FDIRC prototype uses, and replace it with a cylindrical mirror
  - Use a folded mirror design to (a) minimize the size and (b) have detectors accessible
  - Vary: mirror radius, mirror rotation, its distance from the wedge
  - Focus only in y direction, leave a pin hole imaging in x direction.
- **Wedge is a complication compared to the FDIRC prototype:**
  - Define the detector plane using rays, which do not bounce off the wedge walls
  - Rays bouncing off the inclined wedge walls are slightly out of focus.
- **Working to include into the code the resoluions**

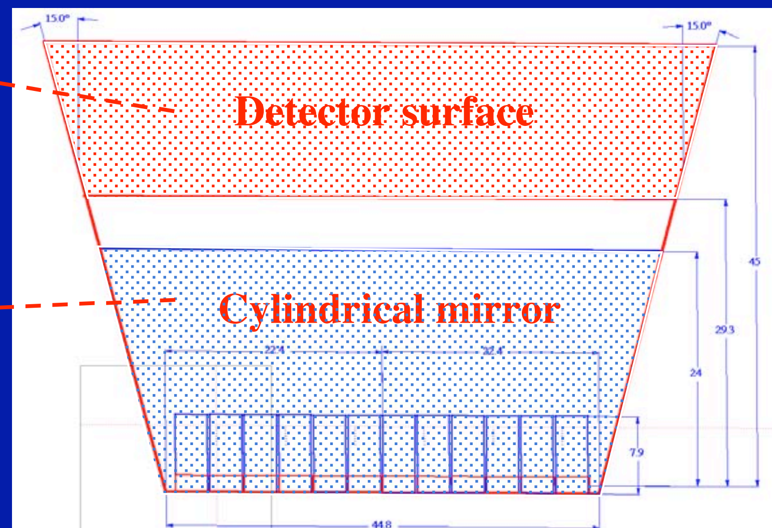
Details of the 1-st design

J. Va'vra, hand ray tracing using a drafting program

Side view:



Front view:



- **Design: cylindrical & flat mirrors & flat detector plane.**
- **Detector surface is formed from rays, which do not strike the inclined wedge surfaces (dashed red).**
- **The images, corresponding to bounces off the wedge inclined surfaces, are slightly out of focus.**
- **Both mirror surfaces must be coated; SOB sides can be just polished.**
- **The SOB is optically coupled to the bar box window using TRV injected in situ.**

Computer code image for $\theta_{dip} = 65^o$

J.Va'vra, ray tracing **in Mathematica**

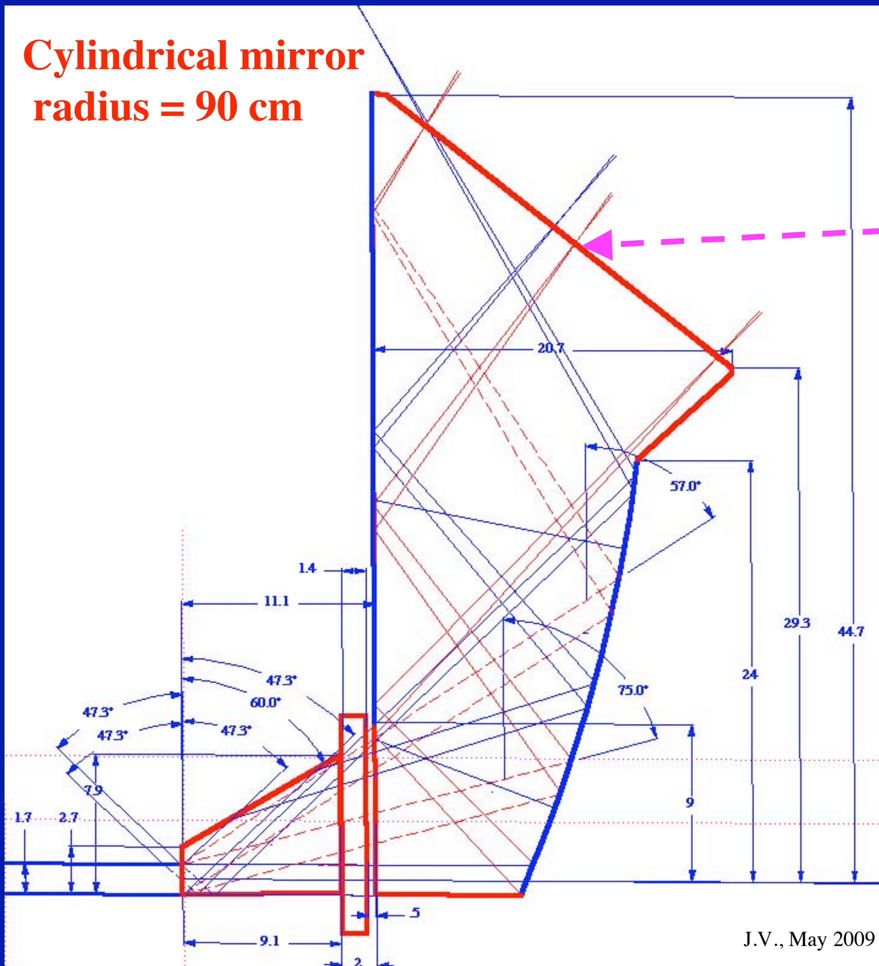
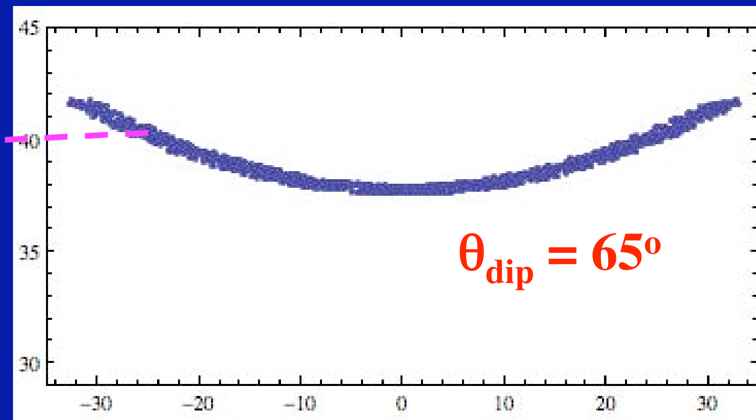
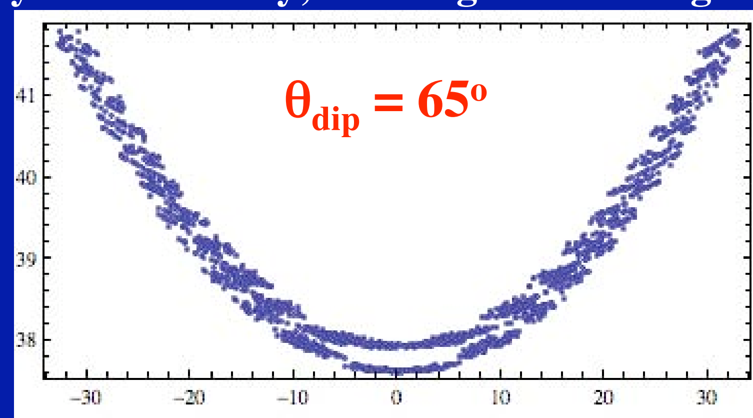


Image for a bar in the center of bar box:



If you look closely, the image hs two rings:



- **The second image comes from the wedge bottom inclined surface.**
- **Observe a kaleidoscopic effect due to bar's squareness.**

Ccomputer code image for $\theta_{dip} = 90^o$

J.Va'vra, ray tracing **in Mathematica**

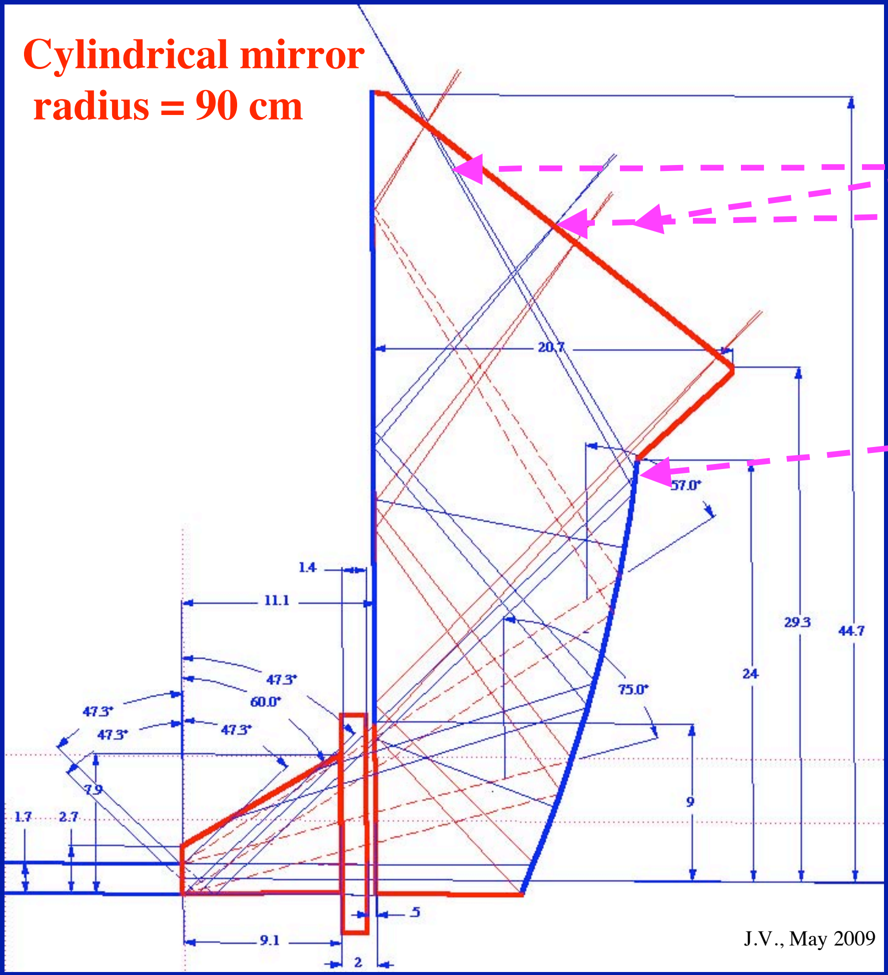
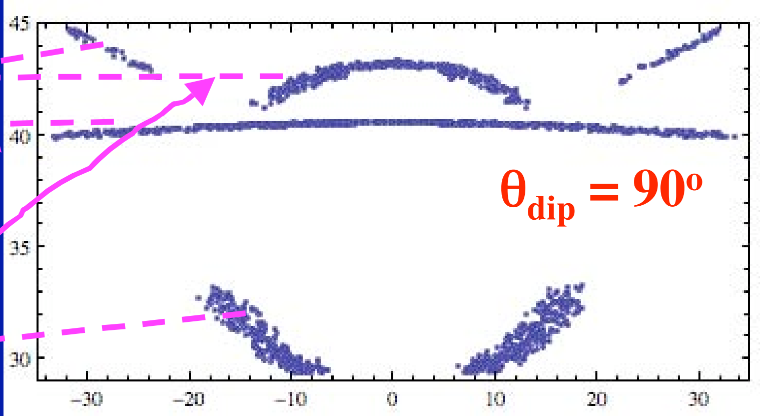


Image for a bar in the center of bar box:



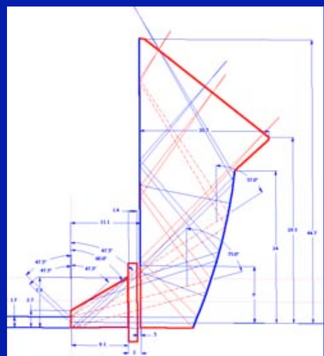
- For $\theta_{dip} = 90^o$, rays are bouncing off the wedge surfaces.
- A portion of the ring, which does bounce off the bottom wege surface and the cylindrical mirror, is "almost in focus".
- However, a small portion of the image, corresponding to a bounce off the bottom surface of the wedge, is not focused at all. This will create a slight tail in the resolution distribution, if one includes these points in the analysis.
- A bounce of the top wedge surface is also slightly out of focus, but it is a better image because the photons bounced off the cylindrical mirror.
- Bounce off the SOB sides.

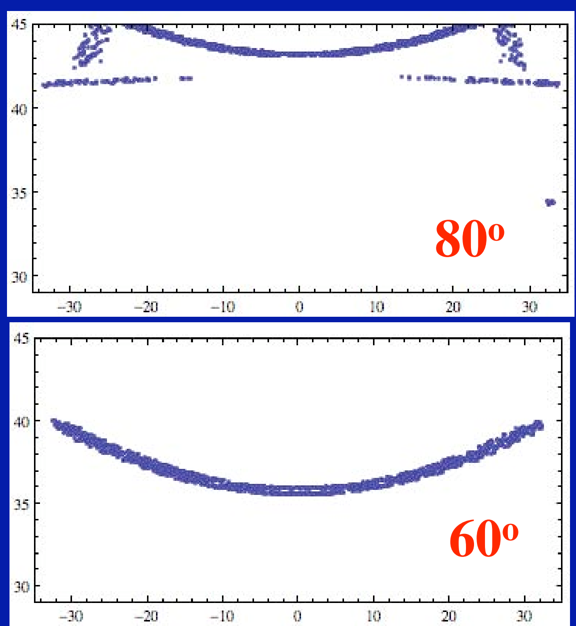
- **Image at 90º is the most complicated**
- **One could make it less complicated by not polishing the SOB sides (?).**

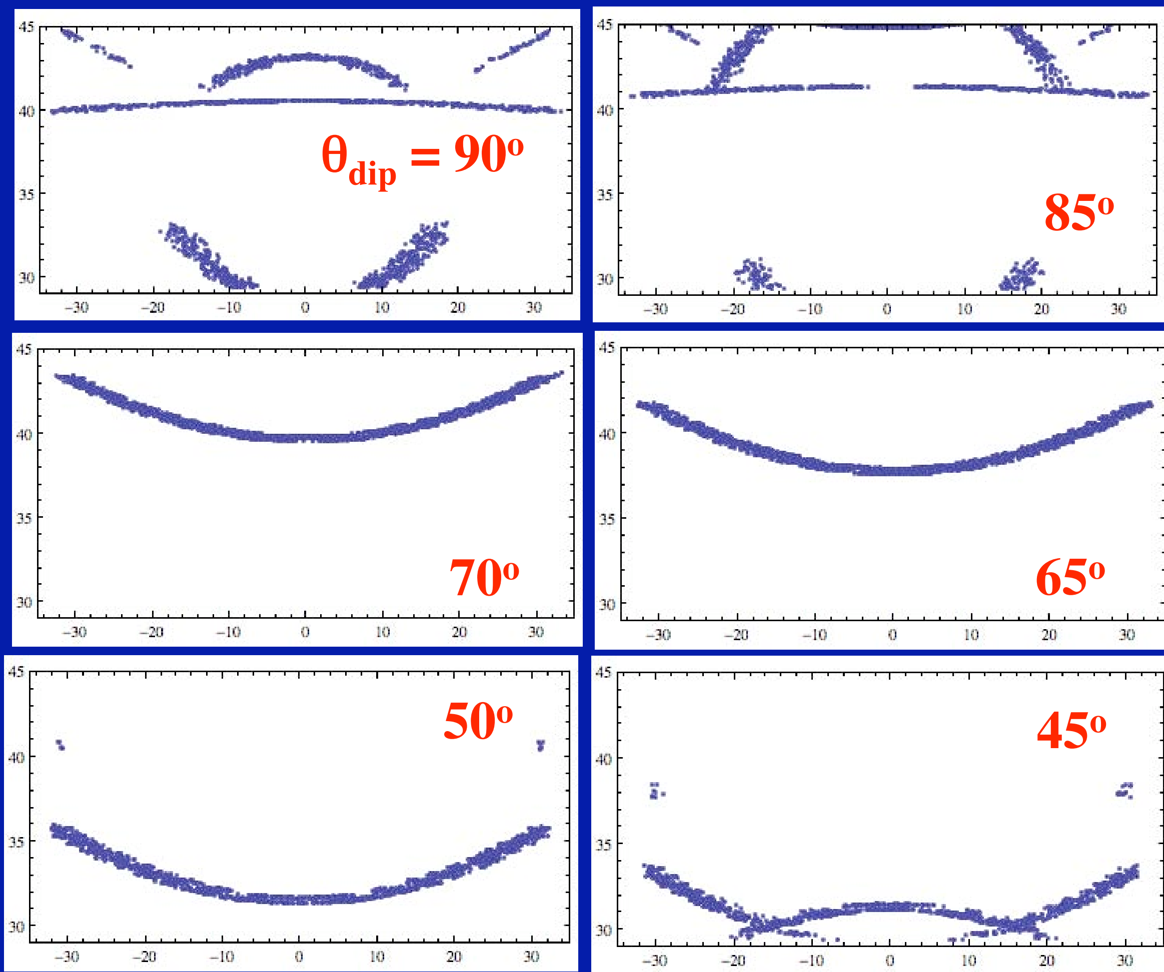
Ring images at different dip angles - R = 90cm

J.Va'vra, ray tracing with Mathematica

Nominal focus:





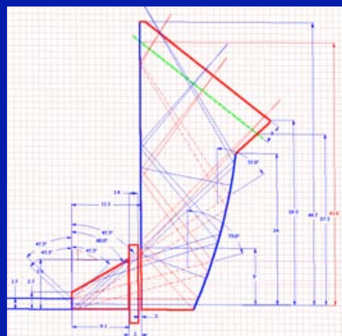


- Cherenkov angle images for different dip angles in the detector plane, which is in focus.
- Seemingly clean images are actually double-images due to the wedge effect.

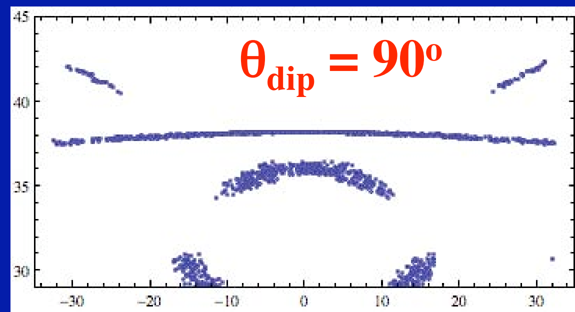
Smaller SOB with slightly underfocused design ?

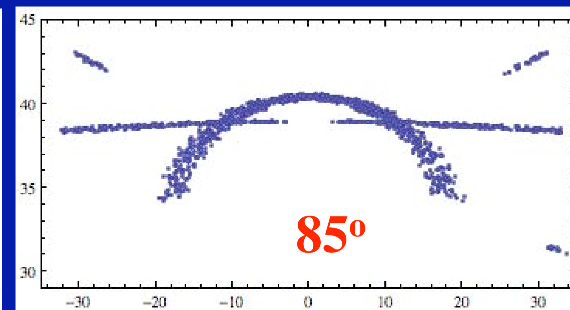
J.Va'vra, ray tracing with Mathematica

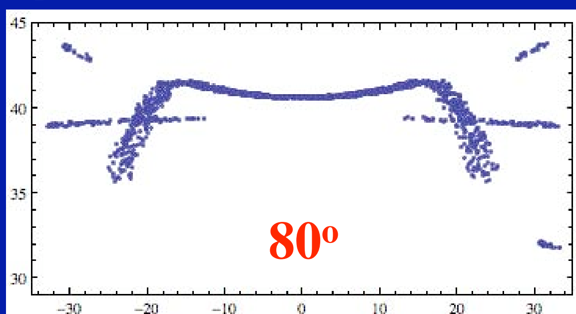
3 cm underfocused:

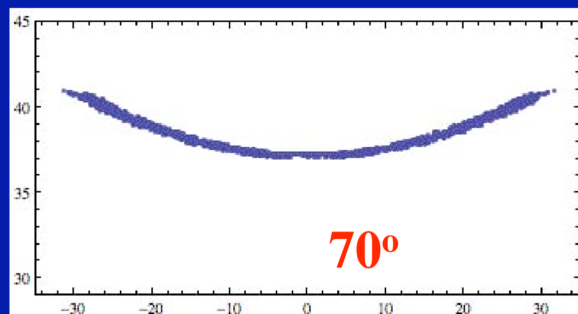


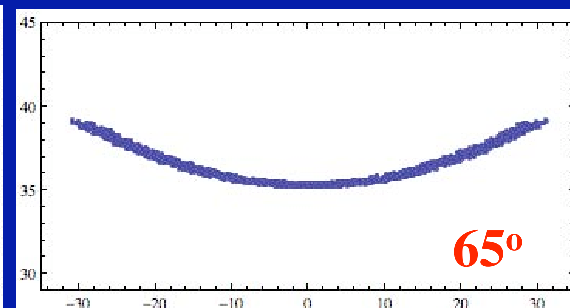
y [cm]

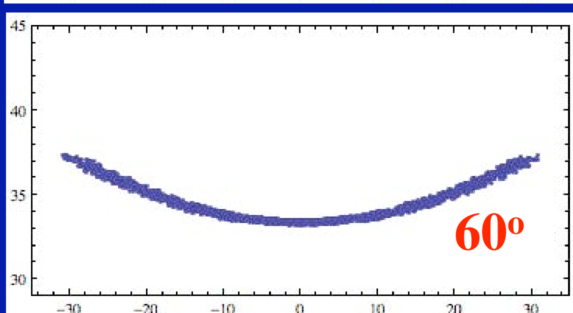


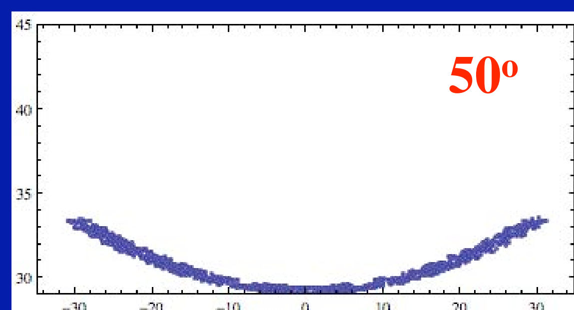


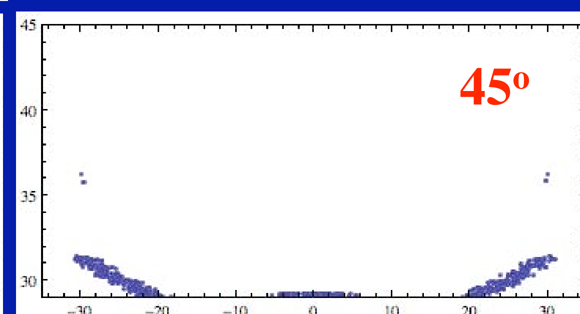












x [cm]

- **Under-focusing is not reaqting an obvious problem.**
- **However, will compare the two designs based on the pixel-based resolutions.**

Plans for the next steps

- **Add all bounces for any bar within the bar box**
- **Decide on a final design geometry (for example, should we make the SOB smaller by slightly under-focusing the detector plane, or should we make the cyl. mirror radius even smaller, tune prediction of a Cherenkov angle resolution in the code, etc.).**
- **If we get LDRD money from the lab, we will build a new SOB piece and couple it to a spare bar box #0, and run it in the cosmic ray telescope (CRT). Will need a help to: a) help to check the design, b) to decide on electronics, c) to analyze data, d) to run MC simulation, etc.**